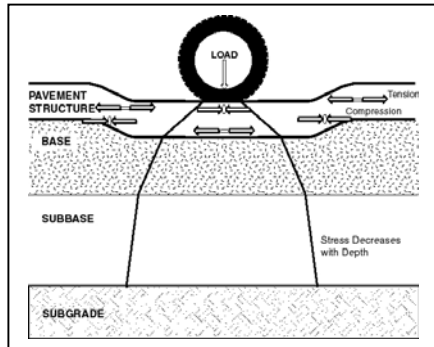
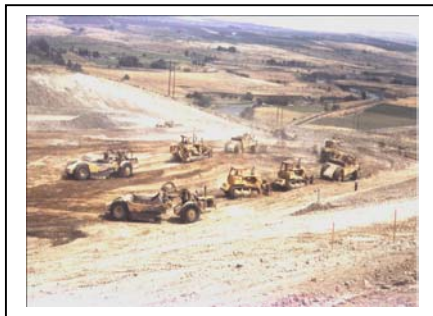


## BASICS OF COMPACTION AND DENSITY CONTROL



Load distribution in roadway  
cross section



Grading

### Introduction

Roadways are constructed in layers. The first layer is the subgrade, or naturally present material. Next comes the subbase, material usually having better structural, drainage, and other properties than the subgrade. This material is sometimes a select material. Above the subbase is placed the base, material of even better quality than the subbase. Finally there is the pavement consisting of either hot mix asphalt (HMA) or portland cement concrete (PCC). In this layered system, structural or load bearing properties improve as we move up from subgrade to pavement. The result is a roadway structure that supports traffic without undergoing excessive surface deflection and/or long term settlement.

Variations to this layering can occur as in roadways constructed on high quality subgrade in which the subbase layer is eliminated. Also to be considered is “embankment”, material between the naturally occurring subgrade and the subbase or base, that is added in “fill” sections of the roadway where the finished road is substantially above original grade.

Stability and durability of roadways is greatly dependent on the finished density of the various components. Low-density subgrade, subbase, base, or embankment will lead to excessive surface deflection under load and/or long term settlement in an amount higher than anticipated. However, compacting these elements to densities higher than necessary is expensive in both time and money.

Quality of roadways also depends greatly on the pavement. In HMA roadways, the density of the HMA plays a significant role in the overall ability to support load and provide long term service. HMA pavement specifications include detail on density as well as percent voids. Under-compaction



**Cracking**



**Sheepsfoot roller**



**Steel roller**

results in low density and high void content. An under-compacted pavement will have low strength, reduced durability, high deformation, and high permeability leading to problems such as rutting, ravelling, and freeze-thaw damage. Over-compaction results in high density and low void content. This pavement may bleed, rut, crack, or have premature failure.

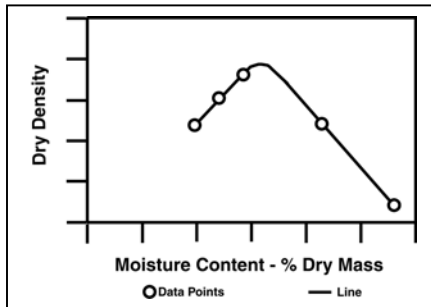
For these reasons, a basic understanding of compaction theory and a thorough knowledge of testing methods is necessary for those involved with construction of embankments and bases, as well as HMA pavement. Compaction equipment and techniques depend on the type of material. Cohesive soils, such as clay, and cohesionless soils, such as gravel, require different compaction methods, and different equipment may be used on HMA than on soils.

### **Fine-Grained Soils**

For fine-grained soils that contain a significant amount of cohesion and little or no internal friction, density depends on compactive effort and moisture content. With these soils, moisture-density relations are key, and two similar test methods are used to determine the relationship between soil moisture and density.

- AASHTO T 99, the standard Proctor test
- AASHTO T 180, the modified Proctor test

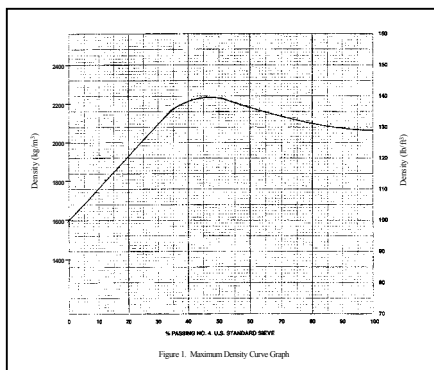
In both methods, samples of soil are prepared at several moisture contents and compacted into molds of specified sizes using manual or mechanical rammers delivering a specified quantity of compactive energy. Knowing the moist masses of the compacted samples and the volume of the molds, moist densities can be determined. Moisture contents of the compacted samples are determined and used to obtain dry density values for the same samples. Maximum dry density and optimum moisture content for the soil are determined by plotting the relationship between dry density and moisture content.



Moisture-density curve



Nuclear moisture-density gauge



Maximum density curve

Construction specifications generally require that the soil be compacted to some percentage of maximum dry density while being maintained at a moisture content close to the optimum. These specified values will be based on AASHTO T 99, or AASHTO T 180 depending on the agency. In the field, dry density and moisture content of the material will be determined using a nuclear moisture-density gauge. The field values will be compared to the specifications to determine conformance with the project requirements.

### Coarse-Grained Soils

For coarse-grained granular soils having little or no cohesion, compactive effort is the primary concern, and moisture content is not as significant an issue because these soils are free-draining and do not retain water. These soils are tested using two general classifications of procedures. The first includes the moisture-density methods discussed above under “Fine-grained Soils.” The second includes procedures that relate density to gradation.

Granular, free-draining materials can be tested by procedures that combine compaction and vibration, as in the Relative Density test. However, various transportation agencies have developed specialized tests that are a hybrid of moisture-density test procedures and relative density determinations, including the following:

- AKDOT&PF’s ATM-12
- ITD’s T-74
- WSDOT’s TM 606
- WFLHD’s Humphrys

In these tests, material is compacted in a mold and in a manner similar to those used in a Proctor test, after which the material is further compacted through a combination of applied loads and vibration. A laboratory maximum dry density is determined, as is the percent of material passing a certain sieve such as the 4.75 mm (No. 4). A number of determinations are made for different percentages passing the specified sieve. A graph is developed in which dry density is plotted versus the

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percentage of material passing that sieve. These tests are conducted in the agency's central lab, and the curve developed is a central lab function.

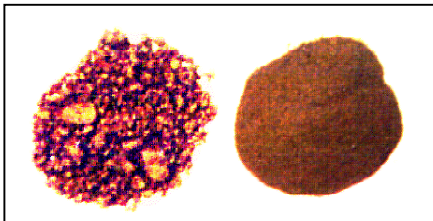
Construction specifications will call out a percent of maximum dry density required for the granular materials used on the job. These specified values will be based on ATM-12, T-74, TM 606, and Humphry's depending on the agency. In the field, the density of the granular material will be determined using a nuclear moisture-density gauge. The percent of material passing the specified sieve will also be determined. These values will be compared with the curve developed in the lab to determine conformance with the project specifications.

### Correction for Oversize Material

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AASHTO T 99, and AASHTO T 180 discussed above are conducted on materials below a certain size, either 4.75 mm (No. 4) or 19.0 mm (3/4-in.) depending on the method. If the material to be tested includes particles in excess of that size, corrections will be required to the maximum dry densities determined. The method used is AASHTO T 224, Correction for Coarse Particles in the Soil Compaction Test.

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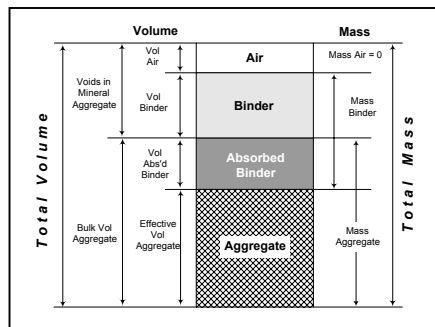
Coarse and fine material

The corrected density is actually a weighted average of the density of the smaller material passing the specified sieve and the larger material retained on the sieve. The density of the smaller material is determined using one of the methods covered above. The density of the larger material is based on knowledge of its bulk specific gravity.

### Hot Mix Asphalt Pavement

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For HMA, density depends on compactive effort as well as the mix design. The gradation and particle shape of the aggregate, the grade of asphalt binder, and the interaction of these have major influences on density and percent voids. The level of compactive effort and the equipment used depend



**HMA phase diagram**

on the mix design properties, environmental conditions and lift thickness.

Construction specifications will call for obtaining a certain percentage of maximum voidless density, as determined in the mix design process, while maintaining voids within a certain range. A specification of 92 to 96 percent of maximum density and a corresponding void content between 8 and 4 percent is typical. In the field, the density of the compacted HMA will be determined with cores and/or calibrated nuclear density gauges and, with this information, the percent voids will be calculated. These values will be compared to the specifications to determine conformance with the project requirements.

### Summary

Proper compaction of soil, aggregate, and hot mix asphalt is necessary for high-quality roadways. Understanding and proper performance of standardized density tests are paramount in obtaining that compaction. The Embankment and Base and/or In-Place Density technician must obtain samples and perform tests in the accepted manner in order to assure the quality of the finished roadway.

